DEVELOPMENT OF A LABORATORY TEST FOR MULTIPORT FUEL INJECTOR DEPOSITS - EVALUATION OF THE JET FUEL THERMAL OXIDATION TEST APPARATUS (JFTOT)

Contract DAAK70-86-C-0011

BY

HAROLD O. STRANGE

FINAL REPORT

CRC CONTRACT CM-128-85 (2-86)

Prepared for

The Coordinating Research Council, Inc.
219 Perimeter Center Parkway
Atlanta, GA 30346

December, 1987

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(Pittsburgh Applied Research Corporation
Final Report on Contract CM-128-85 (2-86)

Sincerely,

Beth Evans
Editor

BE:tb

Enclosures

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DECEMBER, 1987

APPROVED:

T. Robert Rudolf
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Vice-President

FOREWORD

This program was initiated by the Coordinating Research Council, Inc., 219 Perimeter Center Parkway, Atlanta, Georgia 30346 under the direction of the Fuel Injector Deposit Group, Mr. Jack D. Benson, Chairman, CRC Project No. CM-128-85. This program, authorized by CRC Contract No. CM-128-85 (2-86) was initiated January 27, 1987 and completed October, 1987, and was entirely conducted at the University of Pittsburgh Applied Research Center (U-PARC), 100 William Pitt Way, Pittsburgh, Pennsylvania 15238.

The U-PARC Project Leader was Dr. Harold O. Strange who supervised the laboratory test work performed, data analysis and reporting. Laboratory test work (JFTOT tests) were conducted by Mr. Daniel T. Scott, U-PARC - Analytical Services.

ABSTRACT

This report describes the laboratory effort to develop a bench test suitable for screening gasolines to determine their potential for forming deposits in automotive port fuel injectors. The test selected for this work was the Jet Fuel Thermal Oxidation Test (JFTOT) method described in ASTM D 3241.

Tests were conducted at various temperatures and operating conditions on two base gasolines having low and high deposit forming tendency in vehicle tests. In addition, tests were also run on a commercial unleaded gasoline containing detergent additives and on the high deposition fuel treated with varying dosages of four additives claimed to be effective in preventing port fuel injector deposits in vehicle tests.

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SUMMARY

The objective of this program was to develop a laboratory bench test for screening gasolines to determine their potential of forming deposits in automotive multiport fuel injectors. The test would also be useful for evaluation of potential additives designed to remove or prevent deposit formation. Such a test must be repeatable, reproducible and correlate with fuel injector performance in vehicle engines. The work performed in the program reported herein employed the Jet Fuel Thermal Oxidation Test (JFTOT) method and apparatus described in ASTM D 3241.

Two base gasolines having different PFI deposition performance in vehicle tests were supplied by the CRC. Fuel A (High Deposition Fuel) was Ashland's PFI Reference Fuel, Batch 4 and Fuel C (Low Deposition Fuel) was Phillips "J" Reference Fuel, Batch 26. In addition limited tests were run on a typical "good PFI performance" commercial gasoline (M). Finally, tests were conducted on Fuel A treated with varying dosages of four additives and Fuel C with one of the additives claimed by the manufacturers to prevent PFI deposition.

Based on the results obtained, the JFTOT method differentiated between the high and low PFI deposition test fuels and indicated potential performance improvement brought about by use of fuel additives. Acceptable performance was judged by the fuel filter ΔP increases observed in the JFTOT Tests, not by the appearance of deposits on the heater tubes. Inability to reduce or eliminate tube deposits was considered to be due to the much higher temperatures and lower fuel flow rates for the JFTOT tubes compared to actual port fuel injectors. The JFTOT method would appear to be primarily useful as a qualitative Go/No-Go test for quality control testing of gasolines and screening of PFI deposit control additives.

I. INTRODUCTION

With the more widespread introduction of Port Fuel Injection (PFI) in 1984, automobile manufacturers began to experience a growing number of customer driveability complaints due to the formation of deposits in the very small clearance spaces around the injector pintle tip. Deposit formation appears to be related to fuel composition reflecting differences in crude oil quality and processing.

In a paper by R. C. Tupa, of the Lubrizol Corporation (1), it was stated that injector deposits were not formed while the engine is operating either at idle or under normal driving conditions, but only after engine shut down. Thus after about 5 to 6,000 miles of typical intermittent driving the levels of injector deposits can be sufficiently large to result in significant degradation of vehicle performance. This problem can be expected to dramatically increase with the continued introduction of PFI-equipped engines. However, detergent additives and changes in injector design have shown promise toward reducing or eliminating deposit formation.

Presently, vehicle or laboratory engine tests are the only satisfactory means of evaluating the performance of gasolines and detergent additives in PFI-type engines. Because of the time and costs of such test, the CRC Fuel Injector Deposit Group expressed the desirability of development of a laboratory bench test which could be used as a basis for establishing a specification requirement for future automotive gasolines.

The Pittsburgh Applied Research Corporation (PARC) was subsequently awarded a contract to evaluate the potential for using the Jet Fuel Thermal Oxidation Test (JFTOT) method as detailed in ASTM D 3241 as a basis for rating gasolines with regard to port fuel injector deposit (PFI) performance.

The study reported herein reviews JFTOT tests run at different temperatures and operating conditions on two base gasolines submitted from the CRC having low and high PFI deposition performance in vehicle tests. A series of tests was also run on the high deposition fuel treated with varying dosages of four different additives and on the low deposition fuel containing one of the additives claimed by their manufacturers to be effective in preventing formation of PFI deposits.

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(1) "Today's Gasoline Concerns - Injector Plugging and valve Seat Wear", R. C. Tupa, Paper No. AM-86-21, presented at the 1986 National Petroleum Refiners Association Meeting, March 23-25, 1986, Los Angeles, CA.

II. EXPERIMENTAL EQUIPMENT AND PROCEDURES

Evaluation of the deposit forming tendency of various base gasolines and effectiveness of additives to prevent deposits was conducted using the Jet Fuel Thermal Oxidation Test (JFTOT) apparatus and procedure described in ASTM D 3241. In addition to variation in heater tube temperatures, tests were also conducted using some modification (e.g., longer term test, stainless steel tube).

In this test, fuel is pumped at a fixed volumetric rate through a heater tube after which it enters a precision stainless steel filter where fuel degradation products may become trapped. In the standard test, 600 ml of test fuel is pumped at a rate of 3 ml per minute for a 2.5 hour (150 minute) test period. The data derived from this test are the amount of deposits on an aluminum heater tube, and the rate of plugging of the 17 micron nominal porosity precision stainless steel filter.

Figure 1 is a front view of the entire test assembly. Figure 2 is a schematic of the fuel system and Figure 3 is a schematic of the heater tube and filter assembly.

Tests were conducted primarily using the standard ASTM D 3241 conditions and procedure, namely fuel flow rate of 3 ml per minute with a fuel system pressure of 500 psig for a test time of 150 minutes, varying the temperature of the aluminum heater tube. A few tests were also run for a longer time (i.e., 240 minutes) and several tests on the base fuels were run using heater tubes fabricated from type 304 stainless steel.

Fuel filter pressure drop was recorded periodically during the test. After the test was completed the heater tube was rated visually and in addition rated using the ALCOR Mark 8A Tube Deposit Rater (TDR) in which the

tube is spun and the maximum light reflectance rating along the tube is recorded. Figure 4 is an illustration of the Mark 8A TDR device.

Test results are given in Tables 1 through 12, showing the time to reach a filter ΔP of 25 mm Mercury, the filter ΔP at the end of the test (150 or 240 minutes) and the maximum visual and TDR (spun) heater tube ratings. Results are also shown graphically in Figures 5 through 7.

III. DISCUSSION OF EXPERIMENTAL RESULTS

Base Fuel Tests

Deposit-forming tendency of two base gasolines, A (High Deposit) and C (Low Deposit) was evaluated using the Jet Fuel Thermal Oxidation Test (JFTOT) method outlined in ASTM D 3241.

Fuel A (CRC Reference Fuel CRC-9-86A) was Ashland's PFI Reference Fuel, Batch 4 and Fuel C (CRC Reference Fuel CRC-9-86C) was Phillips "J" Fuel, Batch 26. In addition to these two base fuels, a short series of tests on a typical commercial premium unleaded gasoline (containing detergent additives) was also run. Results of the JFTOT Tests are shown in Tables 1 through Table 6 and are discussed in detail below.

Fuel A (High Deposit Fuel) - Table 1 and Table 2

Initial test at 260°C tube temperature showed rapid plugging of the fuel filter and the test was terminated at 22 minutes. The deposit rating on the tube was high even though the test time was only 15% as long as a standard 150 minute JFTOT test. A second test conducted at a tube temperature of 245°C showed rapid filter plugging at 36 minutes and was terminated. Likewise, a test at 230°C showed rapid plugging at 49 minutes and was terminated. One repeat test was conducted at 245°C and four repeat tests were conducted at 230°C tube temperature.

Fuel A (High Deposit Fuel) - Table 1 and Table 2 (continued)

The repeatability in these limited tests appeared reasonable based on the time to reach a filter ΔP of 25 mm Mercury except for one outlier test at 230°C. Time to reach filter ΔP of 25 mm Mercury ranged from 36 to 45 minutes at 245°C Tube Temperature and from 49 to 59 minutes for four of the tests at 230°C. In the other test at 230°C the 25 mm ΔP time as 95 minutes and the heater tube TDR rating was max 18 versus 33 to 40 in the other comparative tests. It is noted that this test was run after two tests were run on additive-treated fuel.

Other tests were conducted at lower heater tube temperatures of 215, 210, 205 and 200°C to further examine the rate of degradation (rate of filter ΔP increase) and maximum tube deposit ratings as a function of temperature. Repeat tests were run at 205 and 200°C tube temperature and included two tests at 240 minutes. As with tests at 230°C, one of the tests at 205°C was run after several additive treated fuels were tested and in this test the rate of filter plugging and deposit formation (i.e., ΔP and 11.0 TDR) was lower than in an earlier test (i.e., 22 mm Hg at 150 minutes and 15.0 TDR).

Fuel C (Low Deposit Fuel) - Table 3 and Table 4

Initial tests at 260 and 245°C tube temperatures indicated rapid plugging of the fuel filter and the tests were terminated at 50 and 85 minutes respectively (filter ΔP of 25 mm Mercury). These times compare with 22 and 36 minutes respectively obtained on Fuel A. The Tube deposit ratings at these temperatures was significantly lower with Fuel C versus Fuel A.

Two repeat tests were run at 260 and 245°C tube temperatures for the full 150 minute time. Repeatability of the 25 mm filter ΔP time showed a greater spread than the Fuel A tests at 245°C. It is noted, however that the tube deposit ratings were quite low in these tests including a 240 minute test at 245°C compared to Fuel A.

Fuel C (Low Deposit Fuel) - Table 3 and Table 4 (continued)

Additional tests were run at lower heater tube temperatures of 240, 235 (two tests) and 230°C (three tests, one for 240 minutes). Repeatability in these limited tests appears fair with respect to filter ΔP increase. Tube deposit ratings were very low.

As with Fuel A, one test on Fuel C at 260°C was run after additive-treated fuels had been tested. Again, in this test, rate of filter plugging and TDR was lower than earlier results. It would seem that despite cleaning the apparatus between tests there is apparently a residual effect due to having tested additive-containing fuels indicating more stringent cleanup is required between tests.

Results comparing Fuel A and Fuel C are plotted in Figure 5 of test time to reach filter ΔP of 25 mm Mercury versus heater Tube Temperature. As can be seen, Fuel C is distinctly lower in deposit formation (filter plugging) than Fuel A.

Commercial Gasoline M (Table 5)

Tests were run at 260, 255 and 245°C (two tests) tube temperatures. In all these tests very low fuel filter plugging was observed even in the 240 minute test at 245°C. Tube deposit ratings in the 260 and 255°C tests were higher than those observed in similar tests of the Base Fuel C, possible indication of additive degradation. However, at 245°C the tube deposit ratings of Fuel M were low and comparable to those obtained with Fuel C.

Figure 6 graphically compares Fuels A, C and commercial gasoline (M) with respect to ΔP = 25 mm Hg time and tube TDR. As is seen, as heater tube temperature is increased from 200°C to 260°C the time to reach filter ΔP = 25 mm Hg sharply decreases and tube TDR increases significantly for Fuel A. By comparison Fuel C does not show a significant decrease in filter ΔP = 25 mm Hg

Commercial Gasoline M (Table 5) (continued)

time until a test temperature of 245°C, while tube TDR remains quite low even at temperatures up to 260°C. For commercial gasoline M, the time to filter ΔP = 25 mm Hg is still above 150 minutes even at the 260°C test temperature used but tube TDR is substantially higher than Fuel C at this temperature.

Comparison of Aluminum versus Stainless Steel Heater Tubes - Table C

Results of limited tests indicate fuel deposition or breakdown is somewhat more rapid with stainless steel heater tubes compared with the standard aluminum tubes, especially for Fuel C (low deposit fuel) compared with Fuel A (high deposit fuel), based on both filter ΔP and tube deposit ratings. TDR of the stainless steel tubes was indeterminate since the base rating of clean tubes was rather high. Visual ratings, though did support more severe deposition with stainless steel tubes.

Additive-Treated Fuel Tests

Tables 7 through 10 show results obtained at various heater tube temperatures for samples of Fuel A (high deposit fuel) treated with varying dosages of four additives, W, X, Y and Z. Table 11 compares results of Base Fuel A and the four additive-treated fuels all at a heater tube temperature of 230°C. Table 12 lists results obtained on Fuel C (low deposit fuel) treated with additive X. Results are discussed in more detail below.

Additive W-Treated Fuel A - Table 7

JFTOT results are summarized comparing Base Fuel A at the tube temperatures of 260 and 230°C with results for additive W-treated Fuel A blends. In some cases tube temperatures up to 275° were analyzed.

Fuel AWH contained the highest dosage of additive W and was considered the cleanup dosage by the manufacturer. Fuel AWL contained the lower keep-clean dosage of additive W. Fuels AWL-50 and AWL-25 were prepared by blending Fuel AWL with Base Fuel A to give fuels containing 50 and 25% of AWL additive dosages.

As can be seen, all the additive W-treated fuels showed very little fuel filter ΔP increase compared with the Base Fuel A. Tube deposit ratings, however, were in the same approximate range as those obtained with the Base Fuel A at the same temperature (e.g., 230°C). As test temperatures were increased (e.g., 260 and 275°C) tube deposit ratings increased but filter ΔP remained low.

Additive X-Treated Fuel A - Table 8

JFTOT results are summarized comparing Base Fuel A and Additive X-treated Fuel A blends at various heater tube temperatures. As with Additive W, AXH is the high dosage fuel (cleanup dose), AXL is the low dosage fuel (keep-clean dose) and AXL-50 and AXL-25 fuels with 50 and 25% of the AXL dosage.

As can be seen, Additive X-treated fuels show very little filter ΔP increases even at temperatures up to 275°C compared to Base Fuel A at 230°C. Tube deposit ratings at various temperatures are comparable to those of the Base Fuel A at the same temperatures, except for Fuel AXH which was somewhat lower at 230°C than Base Fuel A at 230°C.

Additive Y-Treated Fuel A - Table 9

JFTOT results are summarized for Base Fuel A and Additive Y-Treated Fuel A blends at various heater tube temperatures. As before, AYH is the high (cleanup) dosage, AYL the lower (keep clean) dosage and AYL-50 and AYL-25 the 50% and 25% dosages of AYL.

As is seen, Additive Y-treated fuels showed fuel filter ΔP increases and tube deposit ratings comparable to Base Fuel A at the same temperatures, indicating additive Y was ineffective in preventing fuel deposition products from plugging the filter. Limited repeat tests for AYL-50 and AYL-25 showed considerable variability in filter plugging.

It is not known whether the apparent ineffectiveness of Additive Y is borne out in vehicle tests or field performance.

Additive Z-Treated Fuel A - Table 10

JFTOT results are summarized for Base Fuel A and Additive Z-Treated Fuel A blends at varying heater tube temperatures. As before, AZH is the high (cleanup) dosage, AZL the lower (keep clean) dosage and AZL-50 and AZL-25 the 50% and 25% AZL dosage blends.

At the highest dosage (Fuel AZH), additive Z prevented filter plugging even at a heater tube temperature of 260°C while the Base Fuel A showed significant plugging at temperatures as low as 215°C. At lower dosages (AZL and lower) Additive Z exhibited less effectiveness but filter plugging was still somewhat less severe than with the Base Fuel A at similar temperatures. Repeat tests of the AZL dosage level fuel at 230°C showed considerable variability.

Table 11 lists JFTOT results for Base Fuel A and the various additive-treated Fuel A blends all at a heater tube temperature of 230°C.

Additive Z-Treated Fuel A - Table 10 (continued)

As is seen, blends containing additives W and X exhibited excellent performance with respect to filter ΔP increase compared with additives Y and Z. Tube deposit ratings were much less affected giving high values for both neat and additive treated fuels. In this regard, blends containing various concentration of additive X and additive Z at the highest dosage exhibited slightly lower tube deposits than the Base Fuel A and the other additive blends.

With respect to tube deposit ratings, some researchers believe that the additives themselves contribute to the deposits on the tube while at the same time minimizing fuel filter plugging. Thus as shown in Table 11 even the most effective additives with respect to filter plugging still showed high tube deposition. In a breif effort to determine this possibility, a sample of Fuel C (Phillips "J" Fuel) which showed very little tube deposits (Tables 3 and 4) even at tube temperatures up to 260°C, was treated with additive X at the low or keep-clean dosage. As can be seen in Table 12, this additive significantly improved filter plugging performance but showed markedly higher tube deposit ratings compared to the base fuel results. These results would therefore seem to support the suggestion that the additives do show degradtion at the high temepratures employed in the JFTOT method.

Figure 7 is a graphic comparison of the JFTOT results summarized in Tables 11 and 12. As can be seen, additive Y-treated fuels were significantly poorer in performance (i.e., filter ΔP and TDR) compared with the other additive treated fuels.

Additive Z-Treated Fuel A - Table 10 (continued)

Based on an overall assessment of the results summarized in Tables 7 through 11 it is concluded that additive X is the most effective additive with respect to preventing filter plugging in this JFTOT test program. The relative order of effectiveness for the other additives tested would appear to be W > Z > Y. It is not known whether this order of effectiveness is consistent with field experience or vehicle test of PFI deposition.

IV. CONCLUSIONS AND RECOMMENDATIONS

Based on the results obtained in this limited study, we believe that the Jet Fuel Thermal Oxidation Test (JFTOT) method as detailed in ASTM D 3241 has potential as a convenient means for differentiating between various gasolines with respect to deposit forming potential, and could well form the basis for a laboratory quality control test. In addition the test appears to be useful in assessment of additives with regard to reducing deposit formation.

This conclusion, however, is based solely on differences in fuel filter ΔP changes observed at various heater tube temperatures. Results of visual and reflectance (TDR) ratings of deposits on the heater tubes are confusing. While the less stable fuel (Base Fuel A) showed higher filter ΔP and tube deposits than the more stable fuel (Base Fuel C), some of the additive-treated Fuel A blends compared with untreated Base Fuel A showed little or no reduction in tube deposits yet substantial improvement in filter ΔP increases. It was also noted that in a single test, a significant improvement in filter plugging was obtained in the low deposit Fuel C treated with the most effective additive used in this study, but that the tube deposits were very much higher than with the base fuel at the same heater tube temperature. It is noted that temperatures employed in the JFTOT studies are very much higher

than typical engine fuel injector temperatures during hot soaking. While it may be argued that such temperatures are overly stressful and therefore might affect test reliability, it is noted that the original objective was to develop a laboratory test which would correlate with field/vehicle test performance. In order to have a test which would provide such a correlation in a short time (i.e., 8 hours or less) it would probably be necessary to accelerate oxidation/degradation by increasing temperatures or some other means. The final assessment of such tests must await correlation with vehicle tests underway as this report is being written.

In the work reported in the current study it was arbitrarily decided to set the "pass" temperature of the high deposit Base Fuel A with additive treatment at the temperature which resulted in filter ΔP time to reach 25 mm Mercury greater than 150 minutes with the Base Fuel C. As shown in Tables 3 and 4, Fuel C "passed" at 230°C while Fuel A did not (Tables 1 and 2). Some of the additive-treated Fuel A blends thus "passed" at this temperature (Table 11).

Based on this study, the JFTOT method could provide a basis for a Go/No-Go quality control test for base fuels and perhaps be useful in screening additives for potential effectiveness in preventing PFI deposition. In such a Go/No-Go test, a target heater tube temperature for a "passing" filter ΔP would be established based on vehicle PFI deposition performance comparisons of base and additive-treated fuels. Before this can be firmly established, however, more JFTOT testing would need to be run on a variety of good and poor PFI deposition base and additive treated fuels correlating laboratory and vehicle performance. Preferably such evaluation of the usefulness of the JFTOT method would involve a Round Robin between a number of laboratories which would establish test repeatability and reproducibility.

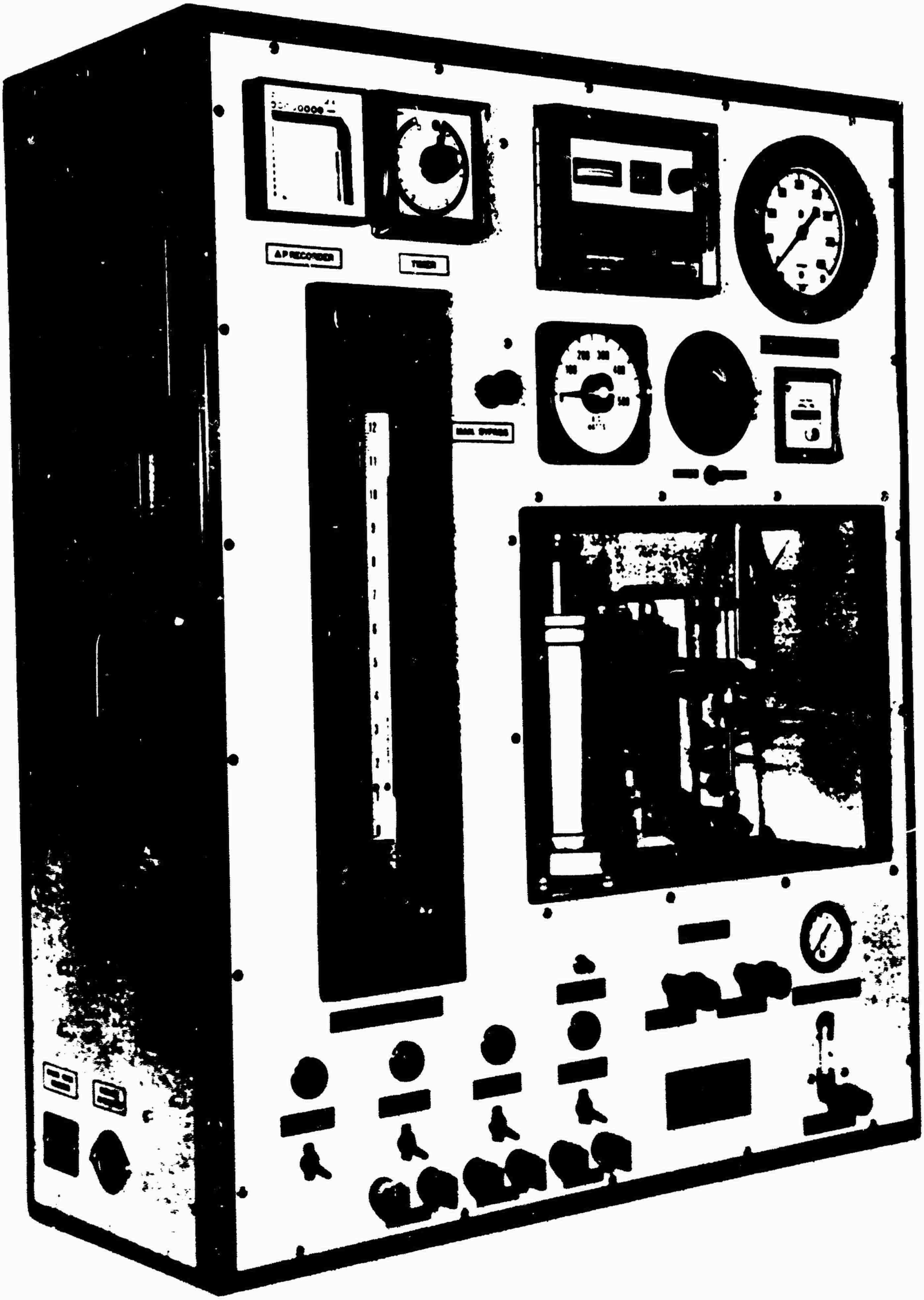


Figure 1

Jet Fuel Thermal Oxidation Tester

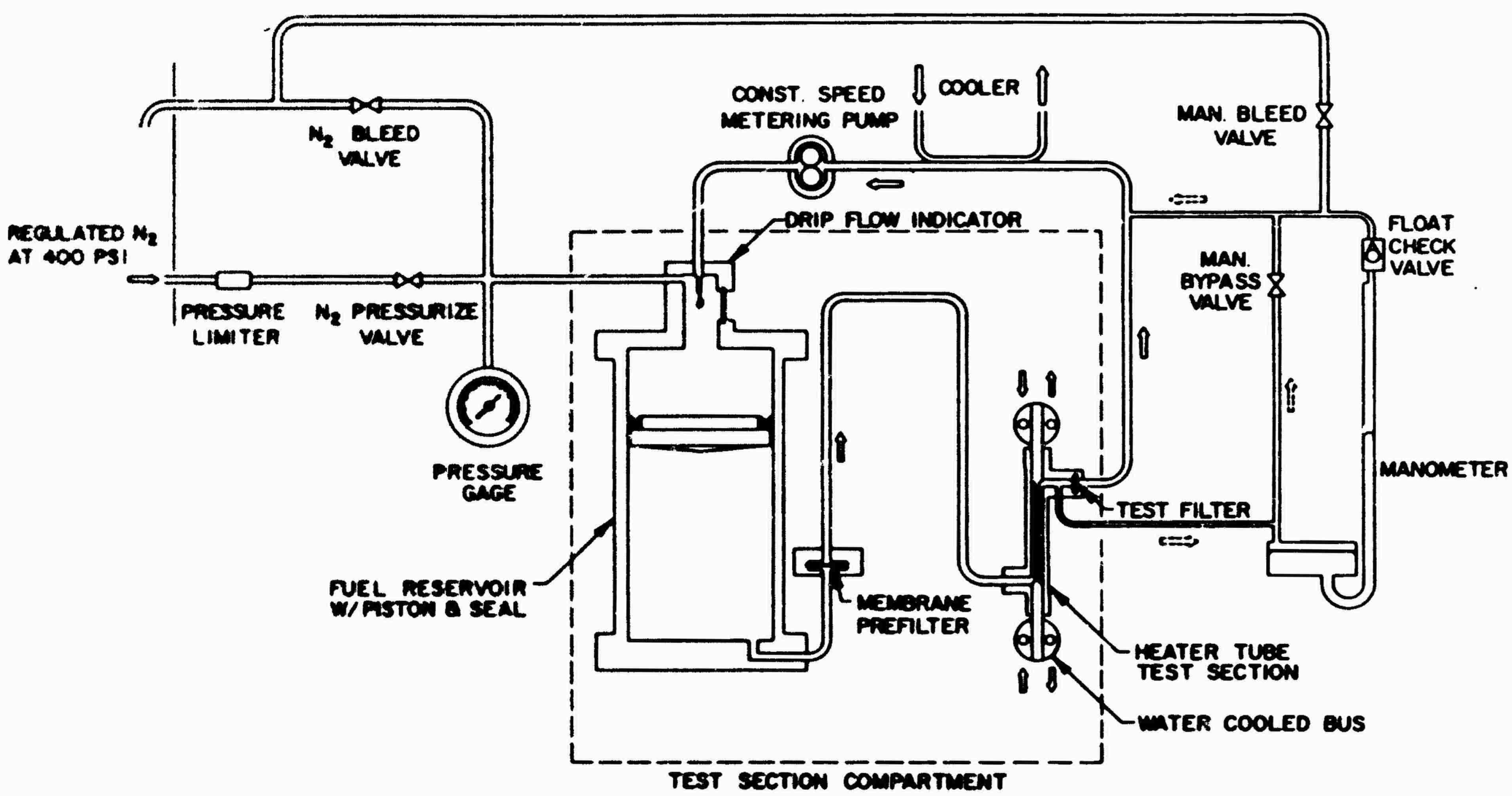


FIGURE 2

FUEL SYSTEM SCHEMATIC

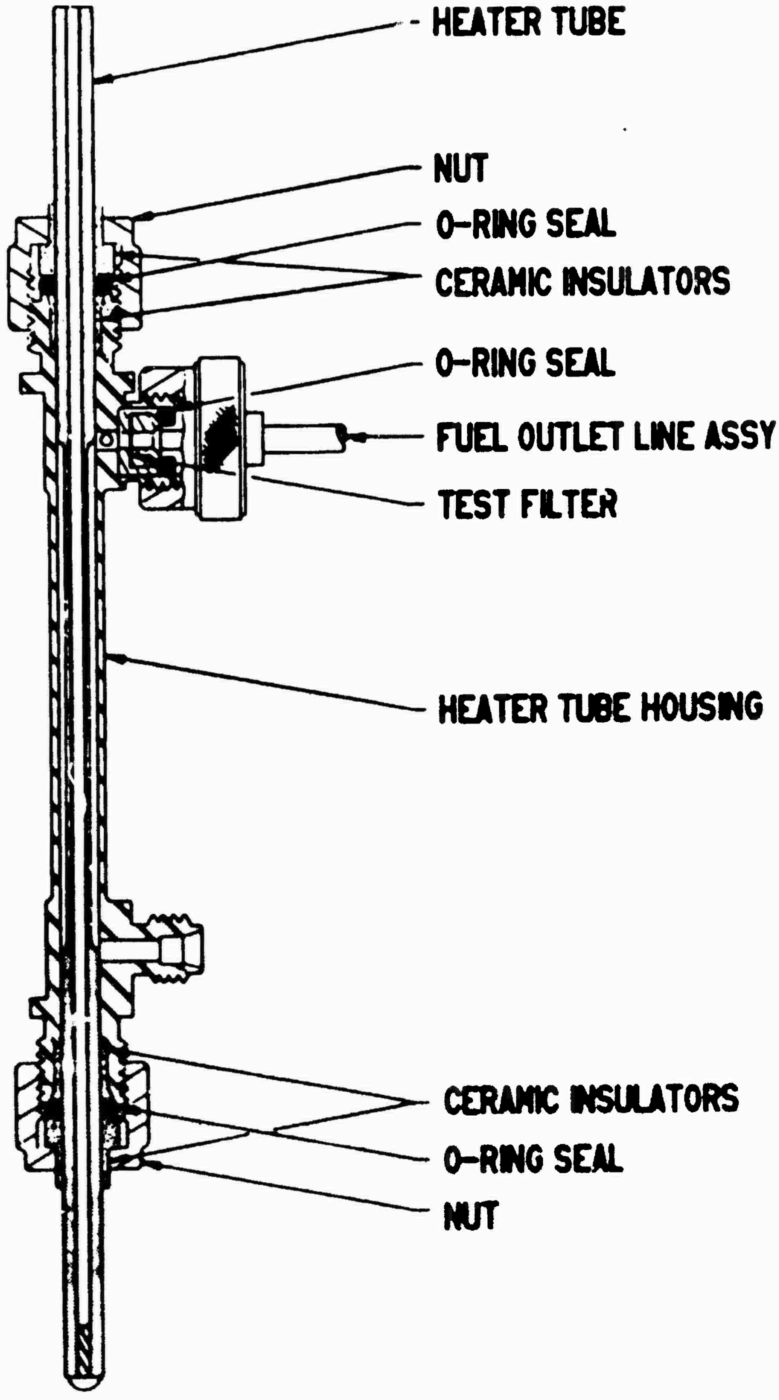


FIGURE 3

ASSEMBLY DRAWING OF HEATER TUBE SECTION

FIGURE 4

ALCOR MARK 8A TUBE DEPOSIT RATER

TABLE 1

JFTOT RESULTS - BASE FUEL A[a]

Filter ΔP vs. Time At Various Temperatures

Tube[b] Temperature (°C)	Time - Minutes to ΔP (mm Hg) 3.0	10	15	25	50	75	100	125	ΔP (mm Hg) At 150 Minutes
260 (500°F)	15	18	21	22[c]	-	-	-	-	-
245 (473°F)	20	25	31	36[c]	-	-	-	-	-
245	34	38	40	45	48	51	61	71	140
230 (446°F)	46	47	48	49[c]	-	-	-	-	-
230	50	52	54	56	62	74	126	-	110
230	40	48	50	53	57	62	101	150	125
230	42	50	55	59	80	98	-	-	85
230[d]	45	53	58	95	-	-	-	-	35
215 (419°F)	60	73	82	91	109	122	-	-	90
210 (410°F)	90	99	112	121	134	150	-	-	75
205 (401°F)	82	123	137	-	-	-	-	-	22
205	-	-	-	-	-	-	-	-	0
205	240	-	-	-	-	-	-	-	-
200 (392°F)	-	-	-	-	-	-	-	-	0
200	240	-	-	-	-	-	-	-	-

a. Ashland PFI Reference Fuel - Batch 4

b. Standard ASTM D 3241 Aluminum Tube

c. Test stopped

d. Test run after several additive-treated fuels were run

TABLE 2

JFTOT RESULTS - BASE FUEL A[a.]

Filter ΔP and Tube Deposit Rating at Various Temperatures

Tube[b.] Temperature (°C)	Time To Reach Filter ΔP = 25 mm Hg (Minutes)	Filter ΔP At 150 Minutes (mm Hg)	Tube Rating At 150 Minutes	
			Max. Visual	Max. TDR (Spun)
260 (500°F)	22[c]	-	3[c]	11.5[c]
245 (473°F)	36[c]	-	3[c]	15.0[c]
245	45	140	4	46.0
	Avg. 41			
230 (446°F)	49[c]	-	3[c]	12.5[c*]
230	56	110	4	40.0
230	53	125	4	37.0
230	59	85	4	33.0
230[e]	95*	35	4	18.0*
	Avg. 54[f]			Avg. 37.0[f]
215 (419°F)	91	90	4	25.0
210 (410°F)	121	75	4	22.0
205 (401°F)	-	22	3	15.0
205	-	0	3	11.0
205	-	3[d]	4[d]	27.0[d*]
				Avg. 13[f]
200 (392°F)	-	0	3	15.0
200	-	3[d]	3[d]	17.5[d]

a. Ashland PFI Reference Fuel - Batch 4

b. Standard ASTM D 3241 Aluminum Tube

c. Test stopped; tube rating at time shown

d. Ratings at 240 minutes

e Test run after several additive-treated fuels were run

f. Average excluding * value

TABLE 3

JFTOT RESULTS - BASE FUEL C[a]

Filter ΔP vs. Time At Various Temperatures

Tube[b] Temperature (°C)	Time - Minutes to ΔP (mm Hg)								ΔP (mm Hg)
	3.0	10	15	25	50	75	100	125	At 150 Minutes
260 (500°F)	43	45	48	50[c]	-	-	-	-	-
260	45	47	50	52	56	60	63	68	150
260	25	27	29	31	35	36	38	42	135
260[d]	7	10	11	14	17	-	-	-	65
245 (473°F)	70	83	84	85[c]	-	-	-	-	-
245	63	72	75	79	84	89	92	96	198
245	104	110	114	118	122	127	135	144	130
240 (464°F)	98	100	101	105	109	113	120	-	109
235 (455°F)	120	124	125	127	138	150	-	-	75
235	112	113	114	116	123	130	138	-	110
230 (446°F)	150	-	-	-	-	-	-	-	3
230	150	-	-	-	-	-	-	-	3
230	150	158	165	167	175	185	199	-	110[e]

a. Phillips "J" Fuel - Batch 26

b. Standard ASTM D 3241 Aluminum Tube

c. Test stopped

d. Test run after several additive-treated fuels were run

e. ΔP at 240 minutes

TABLE 4

JFTOT RESULTS - BASE FUEL C[a]

Filter ΔP and Tube Deposit Rating at Various Temperatures

Tube[b] Temperature (°C)	Time To Reach Filter ΔP = 25 mm Hg (Minutes)	Filter ΔP At 150 Minutes (mm Hg)	Tube Rating At 150 Minutes	
			Max. Visual	Max. TDR (Spun)
260 (500°F)	50[c]	-	1[c]	4.0[c]
260	52	150	1	4.0
260	31	135	1	4.0
	Avg. 44[d]			Avg. 4.0
245 (473°F)	85[c]	-	0[c]	1.0[c]
245	79	198	1	3.5
245	118	130 (135)[e]	1[d]	4.0[e]
	Avg. 94			
240 (464°F)	105	109	0	2.5
235 (455°F)	127	75	0	3.5
235	116	110	0	3.5
	Avg. 122			Avg. 3.5
230 (446°F)	-	3	0	3.5
230	-	3	0	0.5
230	167	3.0 (110)[e]	0[e]	5.0[e*]
				Avg. 2.0[f]

a. Phillips "J" Fuel - Batch 26

b. Standard ASTM D 3241 Aluminum Tube

c. Test stopped; tube rating at time shown

d. Average does not include one test run after several additive-treated fuels were run (see Table 3)

e. Ratings at 240 minutes

f. Average excluding * value

FIGURE 5

JFTOT Results - Base Fuels

Time To Reach 25 mm Filter Pressure Drop

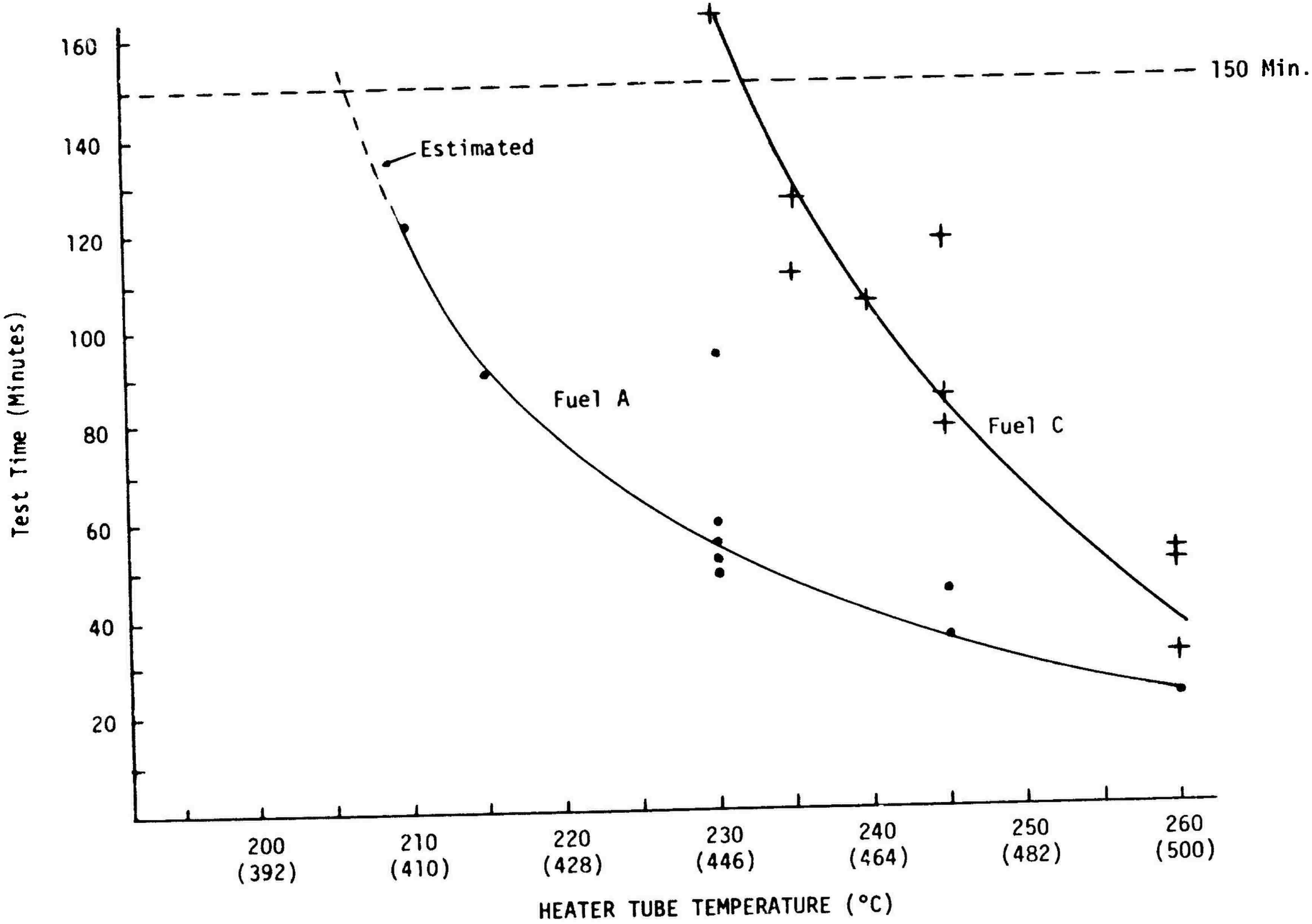


TABLE 5

JFTOT RESULTS - COMMERCIAL GASOLINE M[a]

Filter ΔP and Tube Deposit Rating at Various Temperatures

Tube[b] Temperature (°C)	Time To Reach Filter ΔP = 25 mm Hg (Minutes)	Filter ΔP At 150 Minutes (mm Hg)	Tube Rating At 150 Minutes	
			Max. Visual	Max. TDR (Spun)
260 (500°F)	-	2.0	3	15.0
255 (491°F)	-	3.0	2	12.0
245 (473°F)	-	2.0	1	4.0
245	-	3.0[c]	1[c]	5.0[c]

a. Super Unleaded Gasoline

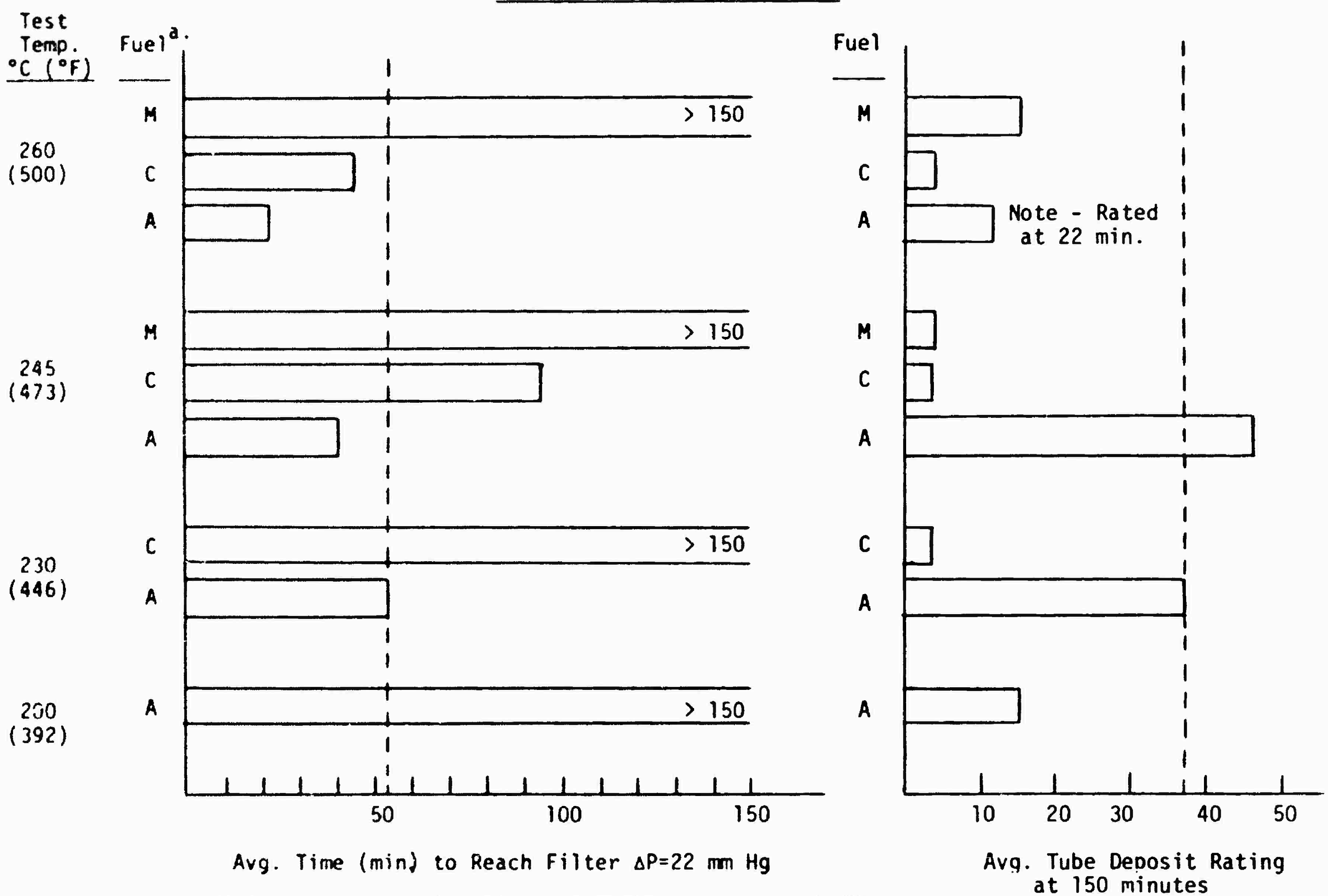
b. Standard ASTM D 3241 Aluminum Tube

c. Ratings at 240 minutes

FIGURE 6

JFTOT RESULTS - COMPARISON OF BASE TEST FUELS AND A COMMERCIAL GASOLINE

Time To Reach Filter ΔP=25 mm Hg. and Tube Deposit Ratings At Various Temperatures



a. M=Super Unleaded Gasoline; C=Phillips "J", Batch 26; A= Ashland PFI, Batch 4

TABLE 6

JFTOT RESULTS - COMPARISON OF
ALUMINUM VS. STAINLESS STEEL TUBES

Filter ΔP and Tube Deposit Rating at Various Temperatures

Tube Metal[a]	Tube Temperature (°C)	Fuel[b]	Time To Reach Filter ΔP = 25 mm Hg (Minutes)	Filter ΔP At 150 Minutes (mm Hg)	Tube Rating At 150 Minutes: Max. Visual	Tube Rating At 150 Minutes: Max. TDR (Spun)
Al	205 (401°F)	A	-	22	3	15.0
Al	205	A	-	0	3	11.0
Al	205	A	-	3[c]	4[c]	27.0[c]
SS	205	A	216	75[c]	4[c]	50+[c,e]
Al	200 (392°F)	A	-	0	3	15.0
Al	200	A	-	3[c]	3[c]	17.5[c]
SS	200	A	-	1	3	49.0[e]
Al	245 (473°F)	C	85[d]	-	0[d]	1.0[d]
Al	245	C	79	198	1	3.5
Al	245	C	118	135[c]	1[c]	4.0[c]
SS	245	C	38	200+[c]	4[c]	50+[c,f]
Al	230 (446°F)	C	-	3	0	3.5
Al	230	C	-	3	0	0.5
Al	230	C	167	110[c]	0[c]	5.0[c]
SS	230	C	133	79	3	50+[f]
Al	245 (473°F)	M	-	2	1	4.0
Al	245	M	-	3[c]	1[c]	5.0[c]
SS	245	M	-	2	3	4.0[g]
SS	245	M	-	3[c]	3[c]	50+[c,g]

a. Al = Aluminum, SS = Stainless Steel
b. A = Ashland PFI, C = Phillips "J", M = Super Unleaded Gasoline
c. Ratings at 240 minutes
d. Test stopped; tube deposit rating at time shown
e. TDR of Tube prior to test ranged from 38.0 to 46.0
f. TDR of Tube prior to test ranged from 45.5 to 49.0
g. TDR of Tube prior to test ranged from 43.0 to 49.0

TABLE 7

JFTOT RESULTS - FUEL A TREATED WITH ADDITIVE W

Fuel[a]	Tube Temperature (°C)	Time To Reach Filter ΔP = 25 mm Hg (Minutes)	Filter ΔP At 150 Minutes (mm Hg)	Tube Rating At 150 Minutes: Max. Visual	Tube Rating At 150 Minutes: Max. TDR (Spun)
A	260 (500°F)	22[b]	-	3[b]	11.5[b]
A	230 (446°F)	49[b]	-	3[b]	12.5[b]
A	230	56	110	4	40.0
A	230	53	125	4	37.0
A	230[c]	95[c]	35[c]	4[c]	18.0[c]
A	230	59	85	4	33.0
AWH	230	-	1.0	4	36.0
AWL	275 (527°F)	-	0	4	50+
AWL	260	-	0	4	50+
AWL	230	-	1.0	4	37.0
AWL-50	260	-	0	4	50+
AWL-25	275	-	0	4	50+
AWL-25	275	-	0	4	50+
AWL-25	260	-	0	4	49.0

a. AWH = High Treat rate

AWL = Low Treat rate

AWL-50 = 50% AWL Treat rate

AWL-25 = 25% AWL Treat rate

b. Test stopped; tube deposit rating at time shown

c. Test run after several additive-treated fuels were run

TABLE 8

JFTOT RESULTS - FUEL A TREATED WITH ADDITIVE X

Fuel[a]	Tube Temperature (°C)	Time To Reach Filter ΔP = 25 mm Hg (Minutes)	Filter ΔP At 150 Minutes (mm Hg)	Tube Rating At 150 Minutes: Max. Visual	Tube Rating At 150 Minutes: Max. TDR (Spun)
A	260 (500°F)	22[b]	-	3[b]	11.5[b]
A	245 (473°F)	36[b]	-	3[b]	15.0[b]
A	245	45	140	4	46.0
A	230 (446°F)	49[b]	-	3[b]	12.5[b]
A	230	56	110	4	40.0
A	230	53	125	4	37.0
A	230[c]	95[c]	35[c]	4[c]	18.0[c]
A	230	59	85	4	33.0
AXH	260	-	0	4	50+
AXH	230	-	0	3	21.0
AXL	275 (527°F)	-	0	4	50+
AXL	260	-	0	4	50+
AXL	245	-	0	4	39.5
AXL	230	-	0	4	31.0
AXL	200 (392°F)	-	0	2	8.5
AXL-50	260	-	0	4	50+
AXL-50	230	-	0	4	26.0
AXL-25	260	150	25	4	48.0
AXL-25	230	-	0	4	26.0

a. AXH = High Treat rate
AXL = Low Treat rate
AXL-50 = 50% AXL Treat rate
AXL-25 = 25% AXL Treat rate

b. Test stopped; tube deposit rating at time shown

c. Test run after several additive treated fuels were run

TABLE 9

JFTOT RESULTS - FUEL A TREATED WITh ADDITIVE Y

Fuel[a]	Tube Temperature (°C)	Time To Reach Filter ΔP = 25 mm Hg (Minutes)	Filter ΔP At 150 Minutes (mm Hg)	Tube Rating At 150 Minutes: Max. Visual	Tube Rating At 150 Minutes: Max. TDR (Spun)
A	230 (446°F)	49[b]	-	3[b]	12.5[b]
A	230	56	110	4	40.0
A	230	53	125	4	37.0
A	230[c]	95[c]	35[c]	4[c]	18.0[c]
A	230	59	85	4	33.0
A	215 (419°F)	91	90	4	25.0
A	200 (392°F)	-	0	3	15.0
A	200	-	3.0	3	17.5
AYH	230	80	31	4	40.0
AYH	215	66	40	4	35.0
AYL	230	90	30	4	40.0
AYL	215	83	33	4	38.0
AYL	215	89	52	4	32.0
AYL	200 (392°F)	-	0	4	22.0
AYL-50	200	88	45	4	30.5
AYL-50	200	-	0	3	10.0
AYL-25	215	-	0	4	21.0
AYL-25	215	5	64	4	25.0
AYL-25	200	-	0	2	10.0
AYL-25	200	-	0	2	9.0

a. AYH = High Treat rate
AYL = Low Treat rate
AYL-50 = 50% AYL Treat rate
AYL-25 = 25% AYL Treat rate

b. Test stopped; tube deposit rating at time shown

c. Test run after several additive-treated fuels were run

TABLE 10

JFTOT RESULTS - FUEL A TREATED WITH ADDITIVE Z

Fuel[a]	Tube Temperature (°C)	Time To Reach Filter ΔP = 25 mm Hg (Minutes)	Filter ΔP At 150 Minutes (mm Hg)	Tube Rating At 150 Minutes: Max. Visual	Tube Rating At 150 Minutes: Max. TDR (Spun)
A	260 (500°F)	22[b]	-	3[b]	11.5[b]
A	230 (446°F)	49[b]	-	3[b]	12.5[b]
A	230	56	110	4	40.0
A	230	53	125	4	37.0
A	230[c]	95[c]	35[c]	4[c]	18.0[c]
A	230	59	85	4	33.0
A	215 (419°F)	91	90	4	25.0
AZH	260	-	0	4	50+
AZH	230	-	1.0	4	27.0
AZL	275 (527°F)	6	61	4	49.0
AZL	230	93	35	4	37.0
AZL	230	-	20	4	29.0
AZL	215	-	0	4	25.0
AZL-50	260	95	40	4	50.0
AZL-50	230	-	22	4	42.0
AZL-25	260	62	42	4	49.0
AZL-25	230	101	42	4	36.0
AZL-25	215	-	0	4	19.0

a. AZH = High Treat rate
AZL = Low Treat rate
AZL-50 = 50% AZL Treat rate
AZL-25 = 25% AZL Treat rate

b. Test stopped; tube deposit at time shown

c. Test run after several additive-treated fuels were run

TABLE 11

JFTOT RESULTS - FUEL A TREATED WITH ADDITIVES

Comparison of Filter ΔP and Tube Deposit Rating at 230°C

Fuel[a]	Tube Temperature (°C)	Time To Reach Filter ΔP = 25 mm Hg (Minutes)	Filter ΔP At 150 Minutes (mm Hg)	Tube Rating At 150 Minutes: Max. Visual	Tube Rating At 150 Minutes: Max. TDR (Spun)
A	230 (446°F)	54[b]	107[b]	4[b]	37.0[b]
AWH	230	-	1.0	4	36.0
AWL	230	-	1.0	4	37.0
AXH	230	-	0	3	21.0
AXL	230	-	0	4	31.0
AXL-50	230	-	0	4	26.0
AXL-25	230	-	0	4	26.0
AYH	230	80	31	4	40.0
AYL	230	90	30	4	40.0
AZH	230	-	1.0	4	27.0
AZL	230	47[b]	28[b]	4	33.0[b]
AZL-50	230	-	22	4	42.0
AZL-25	230	101	42	4	36.0

a. H = High Treat rate

L = Low Treat rate

L-50 = 50% L Treat rate

L-25 = 25% L Treat rate

b. Average values (see Table 2 and Table 10)

TABLE 12

JFTOT RESULTS - FUEL C TREATED WITH ADDITIVE X

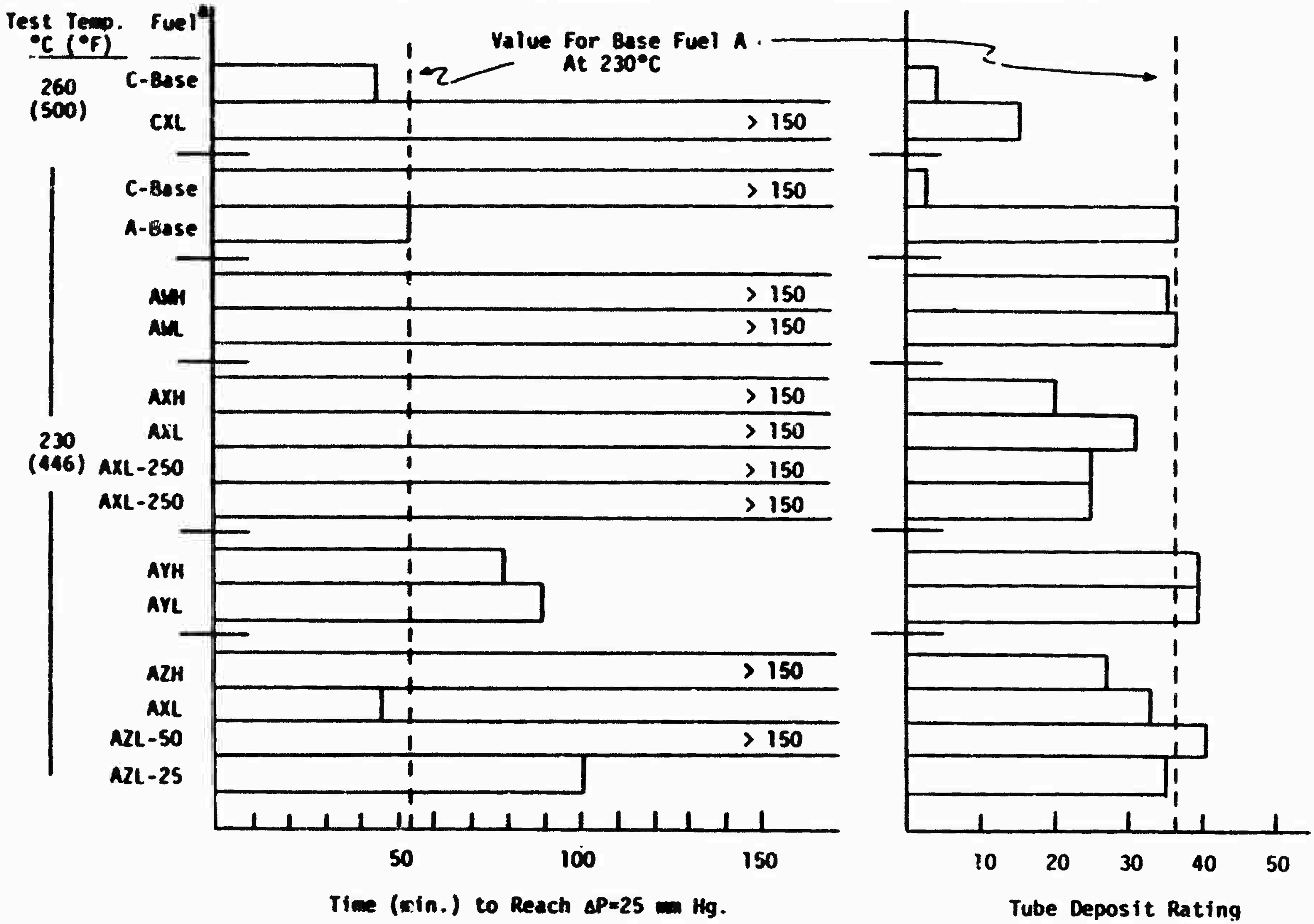
Comparison of Filter ΔP and Tube Deposit Rating at 260°C

Fuel	Tube Temperature (°C)	Time To Reach Filter ΔP = 25 mm Hg (Minutes)	Filter ΔP At 150 Minutes (mm Hg)	Tube Rating At 150 Minutes	
				Max. Visual	Max. TDR (Spun)
C	260 (500°F)	50	-	1	4.0
C	260	31	135	1	4.0
C	260	52	150	1	4.0
CXL[a]	260	-	0	3	16.0

a. CXL = Low Treat rate of additive X

FIGURE 7

JFTOT RESULTS - COMPARISON OF BASE FUELS AND ADDITIVE TREATED FUELS



a. Refer to Tables 11 and 12